Can suggestive hypnosis be used to improve Brain-Computer Interface performance?

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CAN SUGGESTIVE HYPNOSIS BE USED TO IMPROVE BCI PERFORMANCE?

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ABSTRACT:
Improving the user performance is one of the major issues in the Brain-Computer Interface (BCI) field. In this study, the following question is asked: can hypnosis enhance the performance of motor imagery based BCI? Indeed, hypnotic inductions using Ericksonian suggestions can make the user feel simultaneously more relaxed and more focused on the mental task, and therefore could be used to increase performance in BCI. The aim of this study was to evaluate the impact of an hypnotic condition on the ERD/ERS patterns during a kinesthetic motor imagery (KMI) task. To investigate this issue, 19 right-handed healthy subjects performed a KMI of the right hand during two randomized sessions: in normal and hypnotic conditions. We analyzed the event-related (De)-synchronization (ERD/ERS) over the motor cortex and compared the BCI accuracy during both conditions. Our results suggest that the state of hypnosis reduces the ERD phase in the sensorimotor bands, assuming a change in the activation of the motor cortex during the hypnotized state and thus a worst detection of the kinesthetic motor imagery.

INTRODUCTION

Brain-computer interfaces (BCI) allow end users to interact with a system using modulations of brain activities which are partially observable in electroencephalographic (EEG) signals [1]. Originally, BCIs were developed for medical and therapeutic applications, mainly to compensate people with severe motor disabilities. Since several years, BCI progress has been focused essentially to rehabilitate people with severe neuromuscular disorders who represent a very large number of potential users in the coming years [2, 3].
Most of these BCIs are based on the modulation of sensorimotor rhythms during a Kinesthetic Motor Imagery (KMI) task. A KMI is a mental representation which can be described as the ability to imagine performing a movement without executing it, by imagining haptic sensations felt during the real movement [4]. Several studies highlighted the positive effects of KMI practice for people with neurological disorders [5, 6]. These sensorimotor rhythms are characterized i) before and during an imagined movement, by a gradual decrease of power in -mainly- the mu/alpha (7-13 Hz) and beta (15-30 Hz) bands and ii) after the end of the motor imagery, by an increase of power in the beta band. These modulations are respectively known as Event-Related Desynchronization (ERD) and Event-Related Synchronization (ERS) or post-movement beta rebound [7, 8].
A KMI is a highly complex task to be performed by users [9] which makes BCI performance very heterogeneous between studies [10, 11]. Some authors claimed that approximately 15% to 30% of users are not able to gain control of a BCI, a phenomenon sometimes called BCI illiteracy [12, 13]. In this way, Ang and Guan showed that 40% of stroke patients can not achieve the critical BCI accuracy level of 70% and highlighted the critical issue of developing methods for patients to accomplish KMI tasks [14].
In order to improve BCI performance and allow a better control of KMI, it has been suggested that some of altered states of consciousness such as mind-body awareness training (MBAT) [15] or hypnosis [16] can be used. Hypnosis is particularly interesting because several conditions may be induced for patients. For example, hypnotic suggestions can make the subject feel more relaxed and at the same time more focused [17]. Hypnosis is definable as an altered state of attention, receptivity and concentration during which the hypnotized person is captured by a suggestion made by the hypnotist [18, 19]. Although this procedure is already used to reduce pain, manage stress or manage emotional problems [20], we can imagine using it to have a direct impact on the BCI performance, especially by making easier the KMI task execution.
Despite some studies have already shown the interest of MBAT for the BCI domain [21], according to our knowledge, no studies investigated the effect of hypnosis on the EEG signals over the motor cortex and the subsequent impact for BCI performance. Interestingly, Muller et al. showed activation differences between hypnotic and normal states in fMRI for the motor imagery task and suggested that hypnosis enhanced the motor control circuit engaged in the motor task by modulating the gating function of the thalamus [22]. Unfortunately, no studies have yet confirmed their findings and reveal the effect of hyp-

nosis on the EEG signal of the motor cortex during motor tasks.

In this study, the following question is asked: can hypnosis improve MI-based BCI performance? To investigate this issue, 19 right-handed healthy subjects performed a KMI during 2 randomized sessions: in normal and hypnotic conditions. We analyzed the Event-related (De)-synchronization (ERD/ERS) and compared the BCI accuracy for both conditions. Our results suggest that the state of hypnosis reducees the ERD phase in the beta frequency band and thus a worst detection of the KMI task.

MATERIALS AND METHODS

Participants: 19 right-handed healthy subjects (10 females; from 18 to 30 years-old with a mean and a standard deviation of the age of 26.1 years ± 2.8) were recruited for this experiment. This study follows the statements of the WMA declaration of Helsinki on ethical principles for medical research involving human subjects [23]. In addition, participants signed an informed consent which has been approved by the ethical committee of Inria (the COERLE). The subjects had no medical history and no experience with hypnosis which could have influenced the task.

Experimental Tasks: The aim of this study was to evaluate the impact of an hypnotic condition on the ERD/ERS patterns during a KMI task. The motor imagery task was to imagine performing a simple closing movement of the right hand without executing it [24, 25].

Experimental Environment: The experiment took place in a confined room and was conducted by two investigators. The first one assumed the technological process of the experiment. The second investigator was a professional hypnotherapist responsible for instructing the subjects under both normal and hypnotic conditions. During the experiment, the subjects were sitting comfortably on a chair, with their right arm on an armrest, their hand resting on an ergonomic pillow, without any muscular tension.

Experimental Design: The protocol contained 2 sessions: the normal condition and the hypnotic condition. The sessions were performed in a counterbalanced order determined by computerized randomization. For each session, one run of 8 minutes were performed. During a run, the subject had to perform the KMI task during 4 seconds, approximately once every ten seconds. A low frequency beep indicated when the subject had to execute the KMI task. A high frequency beep indicated the end of the task. Breaks of a few minutes were planned between sessions to prevent fatigue of the subject. Before the experiment, the KMI were previously described to the subject and the subject trained to master them without feedback. At the end of each session, participants completed the same questionnaire based on a Lickert scale to assess the possible impact of hypnosis on several criteria (estimated time of the experiment, body perception, memory, detachment, stress, fatigue and motivation).

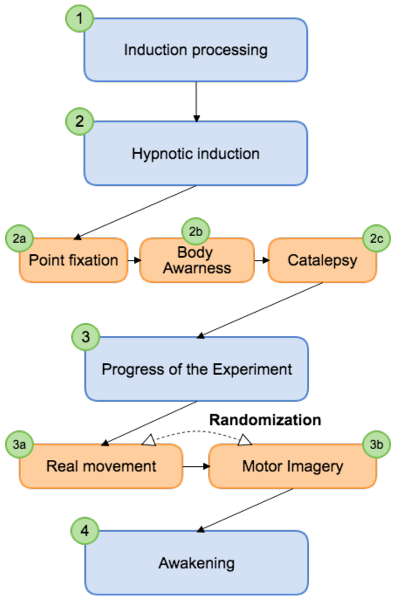

Figure 1: Description of the induction of the hypnotic condition. The Kinesthetic motor imagery was performed after the hypnotic induction composed by a (i) point of fixation, (ii) a body awareness and (iii) a catalepsy with an arm levitation

Hypnotic procedure: The induction procedure was performed by a professional hypnotist. For each subject, a standard script based on Ericksonian hypnosis was used [18]. The Ericksonian hypnosis is characterized by an indirect suggestion by using metaphors. The hypnotic condition was subdivided into several stages: (1) the induction process, (2) the suggestion, (3) the progress of the experiment (KMI executions) and (4) the awakening (Fig. 1).

Physiological Recordings: EEG signals were recorded through the OpenViBE platform with a commercial REFA amplifier developed by TMS International. The EEG cap was fitted with 32 electrodes re-referenced with respect to the common average reference across all channels over the extended international 10-20 system positions. The selected electrodes ware FC_5, FC_3, FC_1,FC_z, FC_2, FC_4, FC_6, C_5,C_3, C_1, C_z, C_2, C_4, C_6, CP_5, CP_3, CP_1, CP_z, CP_2, CP_4, CP_6, P_3, P_1, P_z, P_2, P_4, PO_3, PO_z, PO_4, O_1, O_z, O_2. These sites ware localized around the primary motor cortex, the motor cortex, the somatosensory cortex and the occipital cortex, which allowed us to observe the physiological changes due to the MI task. An external electromyogram (EMG) electrode was added in order to measure the muscle activity. Impedance was kept below 5 kΩ for all electrodes to ensure that background noise in the acquired signal was low.

Time-Frequency Analysis: To analyze the differences between both conditions (normal condition vs hypnotic condition), we performed an event-related spectral perturbation (ERSP) between 8-35 Hz. We used a 256 point sliding fast Fourier transform (FFT) window with a padratio of 4 and we computed the mean ERSP from 1 s before the task to 7 s after the task (Figure 2). ERSP visualizes event-related changes in the averaged power

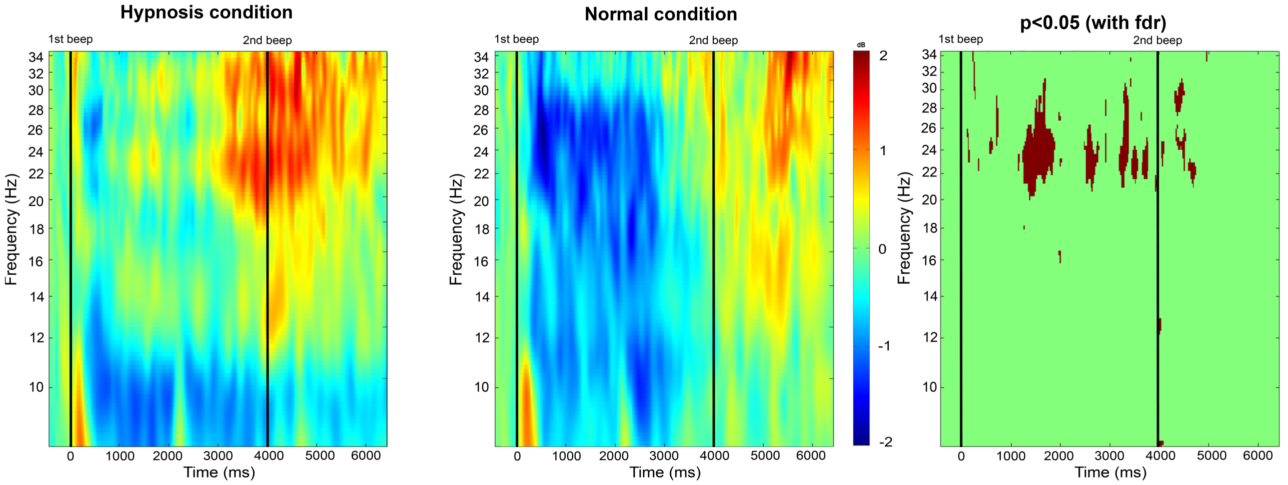

Figure 2: event-related spectral grand average perturbation (ERSP) for MI during normal and hypnosis conditions for electrode C_3. Black lines indicate when the motor task started and finished. A red color corresponds to a strong ERS and a blue one to a strong ERD. Significant difference (p<0.05) with a False Discovery Rate (FDR) correction are shown in the right part of the figure.

spectrum relative to a 2s-baseline interval took 1 s before each trial. A permutation test for a significant level of 0.05 with a False Discovery Rate (FDR) correction using the EEGLAB toolbox was done to validate differences in terms of time-frequency of this ERSPs [26].

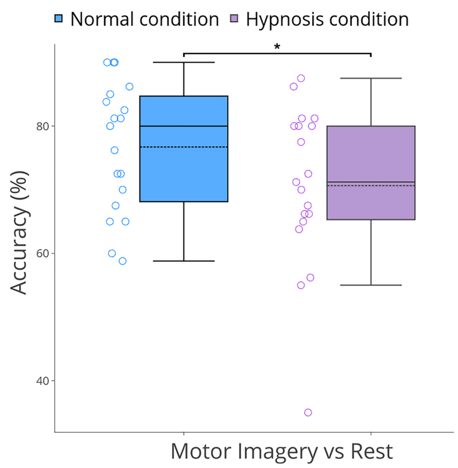

Figure 3: Boxplots showing the distribution of average classification accuracies (N=19) for MI in normal and hypnosis conditions.

Feature extraction: We used the efficient Common Spatial Pattern (CSP) algorithm to extract motor imagery features from EEG signals [27] via the MNE python librery [28]. Pairs of spatial filters have been generated and applied to decompose multi-channel signals into a set of uncorrelated components that simultaneously maximize the variance of one class, while minimizing the variance of the other class [29]. The CSP algorithm has been applied on the whole set of channels which includes electrodes covering the sensorimotor cortex. The number of resulting filters equals the number of EEG channels but for dimensional reduction purpose only the first two pairs (i.e., four filters) were selected.

Once selected filters W were obtained from band-pass EEG signals X, a CSP feature vector f can be computed as follows [30]:

$$f = log(WXX^\top W^\top) = log(WCW^\top) = log(var(WX)) \quad (1)$$

Raw signals were filtered by a 4th order Butterworth band-pass filter using three different frequency ranges (7-13 Hz, 15-30 Hz and 8-30 Hz) to increase the ERD and ERS observations. For each frequency range, trials were cropped from the filtered signals to train two paired CSP filters in time range from 0 till 3 s to maximize differences in variance between the two conditions. Finally we aggregated each 4 features obtained separately for the three frequency ranges into a 12-feature vector.

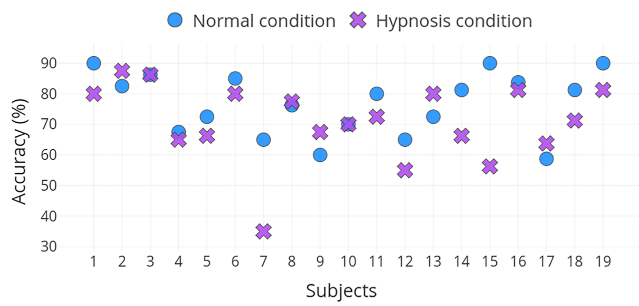

Figure 4: Individual accuracy for motor imagery in normal and hypnosis conditions

Classification: A shrinkage linear discriminant analysis (sLDA) [31] was performed using the Python library scikit-learn [32]. A leave-one-out validation was used to better estimate the accuracy on new trials. A leave-one-out process is K-fold cross-validation with K equal to n, the number of examples in the set. Thus the classifier is trained on all examples except one and a prediction is made for that example [33]. The final accuracy is the sum over all models of correct predictions divide by the total number of examples. We chose to apply a paired t-test (two-sided) to show the significant difference between accuracies obtained for each condition (Figure 3, p-value < 0.05).

RESULTS

Time-frequency analysis: Time-frequency maps display the signal power evolution and are useful to establish the frequency and time windows in which event-related spectral perturbation (ERSP) appears (Figure 2).

During the KMI in normal condition, an ERD appears 400 ms after the first beep and is sustained for 3000 ms in the mu + beta frequency band (8-30 Hz). Note in particular that this desynchronization is predominant in the beta band (18-30 Hz). After the second beep, which represents the end of the KMI, an ERS appears to reach its maximum at 6000 ms.

When a KMI is done in hypnotic condition, an ERD is observable in the lower mu band (8-10 Hz) but not in the high mu (10-13 Hz) neither in the beta frequency bands. Interestingly, an ERS is present before the end of the KMI (at 3500 ms) and is maintained up to 6000 ms.

Comparing both conditions, the ERD disappearance during the hypnotic condition is statistically significant at p<0.05 (with a FDR correction) in the beta band.

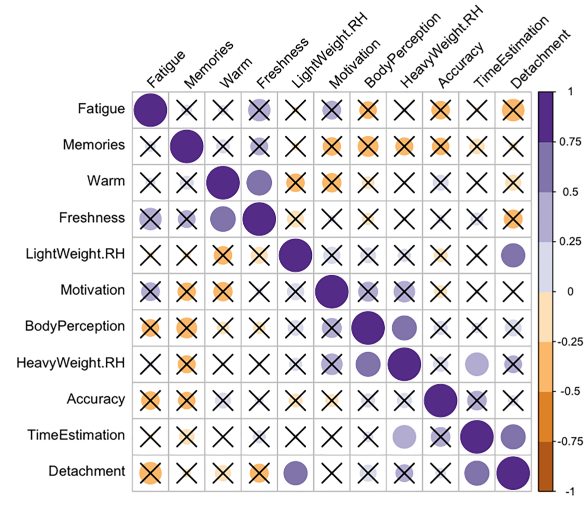

Figure 5: Correlogram representing correlations among estimated time of the experiment, body perception, memory, detachment, stress, fatigue and motivation for normal and hypnotic conditions and accuracy difference between the normal and the hypnotic conditions. Correlations with a p-value > 0.05 are considered as not significant and are crossed out. Positive correlations are displayed in purple and negative ones are in orange. The intensity of the color and the size of the circles are proportional to the correlation coefficients.

Classification:

In order to check if the hypnotic condition could be useful to improve the BCI performance, we decided to compare the accuracy for both conditions. The classification between KMI vs Rest was performed under normal and hypnotic conditions. For both conditions, each trial was segmented into a motor task period and a resting period lasting 3 seconds. Figure 3 shows that BCI performance is significantly better under normal condition compared to hypnotic condition ($76.7 \pm 10.2\%$ VS. $70.6 \pm 12.7\%$). This result is statistically significant at $p < 0.05$. The individual results also show the same tendency, except for 5 subjects: 2, 8, 9, 13, 17 (Figure 4).

Correlogram:

Subjects completed a questionnaire with several items to assess variations between both conditions: fatigue, memories of the experiment, warmness or freshness during the experiment, motivation, time estimation of the task, detachment, change in their body perception, heavyweight or lightweight of their right hand. Figure 5 shows the correlations between these items, to which we have added the *accuracy* representing the BCI performance calculated above. There are some significant correlations ($p < 0.05$) between some items: Detachment and Time estimation, Detachment and Lightweight of the right hand (RH), Freshness and Warm, Heavyweight RH and Body perception, Heavyweight RH and Time estimation. However, no correlation has been established between the variation of the different feelings during hypnosis and BCI performance.

DISCUSSION

In this discussion section, we consider (i) some study parameters, (ii) the hypotheses that could explain why hypnotic state may impact the ERD and (iii) the suggested contribution of such information to the BCI domain.

Study design:

This study was initially conducted on 23 voluntary subjects but only 19 of them were included in this article. Indeed, 4 subjects had anomalously low classification rates (less than 60%) and a time-frequency map without visible ERD and ERS. The subjects who participated were previously selected by the hypnotist as being moderately hypnotizable. We consider that the selection was well carried out since we obtain significantly different results in terms of time estimation, which has already been confirmed by another study [34]. The study was carried out with 32 electrodes, placed only at the pre-frontal, central and occipital area and it would be necessary to confirm the results with a full-head montage. Finally, we reported accuracies using aggregated features from three different frequency ranges (7-13 Hz, 15-30 Hz and 8-30 Hz). Indeed, although not statistically significant, from our experience this method overpass result obtained using features from one frequency range only. Nevertheless, the results between the normal condition and the hypnotic condition were unchanged with a conventional method.

Absence of ERD during the hypnotic state:

Interestingly, the hypnotic suggestion allows to induce multiple states (e.g. be relaxed while focusing on the feelings usually perceived during a real movement), which appears to be particularly relevant to the KMI task [17, 34]. Moreover, after the experiment, a majority of subjects report a more easy way of imagining movement compared to the normal condition. Despite these positive feedbacks, our results showed that hypnosis involves a disappearance of the ERD during the KMI task (Figure 2).

The absence of ERD during hypnosis raises questions. Indeed, Neuper et al. interpret the ERD during the task as being related to a motor cortex activation and the ERS as a deactivation [35]. In this way, the absence of ERD during the KMI task would be due to a weaker activation of the motor cortex, as a consequence of the hypnotic state. This deactivation of the motor cortex could be due to the increase in automation during hypnosis [36]. Further studies had already shown that hypnotic suggestion can modulate the motor cortex activity [37]. However, Muller et al. highlighted that hypnosis could enhance the motor control circuit engaged in motor imagery by modulating the gating function of the thalamus [22], which is inconsistent with our results.

Use of hypnosis for BCIs:

ERD disappears with hypnosis can explain why BCI performance has been impacted. Indeed, the BCI classification is often based on the ERD phase because it is the most robust pattern according to the experimental conditions [8], but also to gain time to provide the end-users with the necessary feedback. If BCI performance was enhanced by the hypnotic state, as it was shown with the MBAT [15], the improvement factors would have been investigated and transferred to the BCI users. For example, designing a self-hypnosis session for BCI illiteracy might be possible. Unfortunately, our average (Figure 3) and individual (Figure 4) results indicate the opposite, and this prompts us to not recommend using hypnosis for BCI applications.

CONCLUSION

This work clearly showed that the hypnotic state has an impact on the EEG through the motor cortex, especially during a kinesthetic motor imagery task. Our results suggest that this altered state tend to remove the ERD during the mental task and implied a negative impact on BCI performance. This prompts us to not recommend using hypnosis for BCI applications.

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